II.

A Memoir upon the Geological Action of the Tidal and other Currents of the Ocean.

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The views presented in the following memoir are derived from a study of the tidal currents on our northern and northeastern shores for the last six years, during which time I have taken part, as hydrographical assistant, in the survey of the coast of the United States, conducted under the able superintendence of Professor A. D. Bache.

This portion of our coast abounds in alluvial and subaqueous deposits, the most numerous, and perhaps the most striking, examples of which occur on and about the island of Nantucket. It is particularly in the survey of this district that I have been led to trace the connection between the currents and the shoal formations which give a peculiar character to its navigation. The changes that are supposed to take place in these shoals are the subject of popular inquiry, and this inquiry could only be satisfactorily answered by an investigation into their mode of formation, and the probable causes that determine their shape and locality.

Having arrived at some definite views concerning the relation of the currents in this immediate vicinity to the deposits below the surface, and to those that have been raised above the water by the transporting power of the winds, such as hooks, beaches, &c., it was an easy and natural step, first, to extend the reasoning suggested by these humble instances to the more grand subaqueous and alluvial deposits at a distance from this continent, on the shores of Europe, and elsewhere; and afterwards, remembering that the laws of nature are constant, uniform, and universal, to consider how far the same modes of operation have been employed, in previous geological periods, in distributing or collecting the loose materials of the earth's surface.

Whilst occupied with these inquiries, it was my good fortune to have with me, as a guest, Mr. Edward Desor, a gentleman too well known in the world of science to need

any commendation at my hands. He entered cordially into my views, assisted me in gathering and arranging the details of this memoir, and supplied, from his abundant stores of ready knowledge, the most conspicuous and valuable examples of tidal and current action in past geological ages.

It has been suggested by Mr. Desor, as well as by other friends in whose judgment I have great confidence, and who, like himself, were not previously familiar with the subject of the tides generally or with the nature of tide-currents, that this memoir would be more intelligible if it were preceded by a short treatise upon the dynamical action of the tides, and of the streams generated by resistance to the motion of the tidal undulations, or by other causes affecting the condition of the ocean. But it has been considered, on the other hand, that the object of this memoir is to introduce a new theory to the notice of the scientific world, which has already in its possession the means of testing the accuracy of the principles upon which the theory is based. The long and able series of "Researches on the Tides," by Dr. Whewell, have supplied the necessary information on this subject; and any statements comprising such practical details as come under the special observation of the hydrographer will be referred to competent authority.*

The satisfactory treatment of this subject, moreover, would embrace a wide range, commencing with the theoretical origin of the tidal currents, and terminating with graphical illustrations of the variable and complicated action of streams passing from the open sea into wide bays, meeting in sounds, conflicting with the courses of rivers, or following the irregularities of an indented and broken coast: it must also include some of the ocean currents. It has been thought best, therefore, upon reflection, to defer a popular account of the following views to another time and place. This account will embrace the distribution of the coralline detritus, which belongs equally to the subject, though designedly omitted in this memoir.

Section I. — *Upon Shoals, and their Relation to the Currents of that Part of the Sea in which they are found.*

There are certain inequalities in the bottom of the ocean, particularly that part of it near the land, which give a distinctive character to the navigation of the region in which they are found. The inequalities to which I refer are known by the generic name of

* I have referred particularly to the "Researches" of Dr. Whewell, rather than the discussions of Sir John Lubbock; because it is the form, progress, transmission, interference, &c., of tide-waves, and the establishment of ports, that are to be dealt with, and not those variable phenomena of the tides depending upon changes in the moon's place or upon atmospheric influences.

shoals, by which is meant formations composed of loose and light materials, easily suspended by the water, and carried about by its motions and agitations.

Shoals, in the vocabulary of seamen, are, strictly speaking, spots of shallow water, dangerous to vessels, generally isolated in situation, of comparatively small extent, and rising from the surrounding ground in such a manner as to interrupt the channels in or near which they lie. Shoals are most frequently found in great numbers in the same place, and not, like rocks, single; this feature of their existence is connected with, and dependent upon, the form and material of the neighbouring land. They are also found where there are currents caused by the flux and reflux of the tide, by the regularly uniform changes of the ocean, by occasional and local disturbances, or by the conflict between rivers and the waters into which they empty.

Examples of shoals the most striking in number, extent, and relative position are to be met with where the action of the tides is equal, permanent, and marked, and where the land around which they are deposited is composed of materials similar to their own. Such is the case on the southeastern coast of New England.

The navigation here is rendered peculiarly dangerous by numerous shoals, among which the tides ebb and flow with regularity, having a rise and fall of four or five feet; and the shores both of the continent and islands consist almost entirely of the same mineralogical substances as the shoals themselves.

From among these, that group known as the *Nantucket South Shoals* has been selected as the most characteristic, and as the best suited to illustrate the views which it is the object of this memoir to disclose. Occasional reference, however, will be made to other shoals on the southern coast of Massachusetts.

It will be readily observed, upon an inspection of the chart of the Nantucket Shoals (Plate I.), that there is a conformity between the shores of Nantucket island and the shoals themselves in their place and direction. On the south side of the island, where the shore runs east and west, the shoals called the "Old Man," "Old South Shoal," and "New South Shoal," lie more nearly in that direction than on the east side. There they follow the north and south direction of the island. There is but little doubt that a complete survey of this region will assign the same general conformity of outline to the external soundings. Numerous specimens of the shoals have been collected, and they are found without exception to be identical in composition with the island. Nantucket, as may be easily seen at the sandy bluffs in any part of the island, is composed of quartzose sand deposited in layers; which is the material of the shoals also, with this difference, that the sand of the latter is somewhat finer, as if it had been subjected for a longer time to the action of water.

This correspondence in direction and similarity of material imply the existence of an intimate relation between the deposits above and below the water; and as it is apparent that the causes which have produced the latter, whatever they may be, are not sudden or accidental, but, on the contrary, continued and regular, it is to be expected that the same or similar causes should now be discovered in operation.

The most prominent feature of a shoal, which is its rise above the ordinary level of the surrounding ground, proves that the mode of its formation is different from that of the bottom of an inclosed basin of quiet water, where the matter in suspension is deposited horizontally. This difference has been attributed to the action of the waves of the sea. If this supposition were true, shoals should be more numerous than they really are, and they should be constructed according to the direction of the prevailing winds. Lakes, moreover, are wanting in shoals, which would not be the case if they were produced by waves alone. The effect of the agitation of water by waves over a nearly uniform surface is to distribute materials, not to heap them up; as is shown by the level bottom of a shallow pond. That shoals are not the result of wave-action alone, then, is proved by the universal fact, that their form has no connection with prevailing winds, by their absence in lakes, and by the general distributive, rather than constructive, tendency of waves.

Recurring again to the similarity of materials of the shoals and the adjacent land, to the facility of their transportation, and to the regular and constant movements of the water effected by the tides, it remains to consider the influence of the tidal currents. If this influence operates, it should show itself in various ways; the shape and direction of the shoals should correspond to the course and action of the tides. The Nantucket South Shoals are in general long and narrow. They lie where the daily ebb and flow of the tides are rapid and, during the greater part of their period, steady in direction; and the direction of the tides is also that of the shoals. The south shore of the island, from Smith's Point to Siasconsett, runs, as was said before, east and west. At Siasconsett the land turns gradually to the north, so that the shore from this place to Great Point lies nearly north and south.

The tides that cause the flux and reflux of the waters pressing upon the island follow the outline of its shores. The flood, for example, commencing with a nearly easterly direction on the south side, passes gradually round to the north on the east side, following the trend of the land. The reverse is the case with the ebb. As the distance from the shore increases on the south and east sides, the direction of the tides is modified by the remoter influences which govern the progress of the tidal wave along this part of the coast.

It may be stated, in general terms, that the tidal wave which supplies this part of the coast approaches it in a direction between north and west, but is deflected to the east by the banks that lie between the Gulf Stream and the main, known in the technical language of seamen as "soundings on the coast." The general course of these banks answers to that of the shores, which from New York begin to turn to the eastward. Farther from the island of Nantucket, therefore, the easterly direction of the flood inclines to the northward, and the westerly direction of the ebb to the southward. Now, the shoals in the vicinity of Nantucket conform so nearly to the courses of the tides as to leave no doubt that they are indebted to them for their form.

The shoal called the "Old Man," on the south side (see Plate I.), lies nearly east and west, while the "Bass Rip" on the east side has a north and south direction.

The "Old South Shoal," at a distance of twelve miles, and situated where the flood tide takes a more northerly course, lies about northeast and southwest.

Without multiplying these instances, it can be safely asserted that the same law of conformity is exemplified in all the principal shoals of this extensive group. This view is further illustrated by noticing the configuration of these shoals, which as a whole may be regarded as a system of curved elevations concentric with the island of Nantucket, and though the members of any one series may be separated by deep water suited to the purposes of navigation, yet the relation below the surface can be frequently traced, either by similarity of material, or by comparatively smaller depths along their line of connection. These separations must be regarded as the channels preserved by the flow and ebb of the tide, through which the great body of the water that passes among the shoals finds its principal vents.

Between the several series, the intervening space is marked by striking differences of depth and bottom. The shoals themselves are composed, as has been said, of sand; but in the valleys between there are dead shells, coarse gravel, pebbles, and stones, the latter abounding in animal life, in which the shoals are entirely deficient; showing that there is not merely a difference of level, but a real distinction in origin and composition.

Hitherto I have spoken principally of the form and composition of the shoals in their relation to the bottom at large; but there are peculiarities in their individual structure worthy of special notice on account of their close resemblance to certain forms common in the drift deposits of New England and Northern Europe. One of the most striking of these peculiarities is the ridgy character. The top of the shoal is not an even surface, like a plain, but its outline is rounded, and frequently broken into several long and narrow summits, or ridges, crowded closely together, and in general parallel to the main axis of the shoal.

The depth of water on the shoal is so small, that the top is subjected to a destructive action of the waves and currents, producing other inequalities of level. There are drains or "slues," as they are called by seamen (probably a corruption of *sluices*), through the ridges, similar to the channels in the deltas of rivers. These drains result from the agitations of the sea, and from the lateral pressure of the tides, which, running parallel to the direction of the ridges, and being higher than their summits, are forced over them, so that *at* the shoals the tides, both flood and ebb, appear to run at right angles to their real line of direction.

The drains or slues run in the direction of the ebb tide. This is in accordance with the prevailing law of operation of the tides, which makes the ebb the most influential in preserving and creating channels.

To return to the materials of the shoals. The particles of sand, even the most minute, are smoothed and rounded by the action of the water; they appear to be finer as they are farther from the shore, and in their mineralogical character they agree exactly with the sand of Martha's Vineyard, Nantucket, and, it may be added, the coast of Cape Cod.

Parts of these islands undergo constant changes, sufficiently rapid to be plainly perceptible in a few years. I have undoubted testimony, from living and intelligent witnesses, that the beach extending along the southeast part of Martha's Vineyard has been washed away for the breadth of one mile in the term of fifty years, leaving the remains of the former beach as a line of detached shoals, between which and the present shore there is now deep water. In 1839 – 41, the cliff or bank at Siasconsett fell twice, carrying with it the last time about twenty-five feet of the top. One dwelling-house, and some small buildings, were precipitated into the sea. Several other houses standing on a line with these were saved by being moved in time. These disasters were caused by an unusually high tide, and by a violent gale from the east-northeast. The destructive action of the waves upon prominent headlands is well understood. At a point in the Vineyard Sound called West Chop (see Plate I.), the light-house was removed two years ago farther inland, the water having washed away and undermined that part of the bank on which the old light-house stood. A similar change is taking place at Cape May, and many such instances might be cited from books of authority; but the general fact is too well known to require additional confirmation.

From these sources, then, there proceeds a constant supply of loose materials, which are subjected to the action of the water. These materials are undoubtedly carried away by the currents, and as the shoals or other deposits are found in their course, it is a necessary conclusion that they are the products of their action. But there should exist some

cause why the suspended matter is found in particular places, and in great quantities; and this cause, it may be readily conceived, must be the natural inequalities in the level of the bottom, which, interrupting the stream, not only take up a portion of its burden, but occasion the eddies that, as I shall have occasion to show hereafter, are especially favorable to deposit. The inequalities need not be very great. Small impediments at the mouths of harbours, or in rivers, serve this purpose of a nucleus. A vessel sunk in a spot where the water is loaded with sand or mud collects around it a deposit by which it is wholly covered in a short time. This is often exemplified on various parts of our coast. Where the attempt has been made to rescue valuable property from ships that have remained for a long time sunk in such places, a part of the task has generally been to remove the covering under which they were buried. At the late meeting of the American Association for the Promotion of Science, Mr. Dickeson related a remarkable incident of this kind, where, at the island of Galveston, in 1839, a vessel from New Orleans was wrecked (at the south end), with a considerable amount of specie. The officers of the custom-house took immediate measures to recover the valuable cargo, and in a little time the workmen reported the vessel to be nearly covered with sand.

How far the eddying of the water produced by the interruption assists in the formation of the shoal will appear more plainly when considering the effect of interruption and diversion of the tidal current by points of land. The results, so far as the eddying action is concerned, are similar in each case, and it is no doubt safe to say that this condition is the only one under which a deposit can take place in a strong tide-way.

In an inclosed space, like Vineyard Sound, shoals are formed both by the ebb and flood tides; their direction is parallel to the course of the tides, the place from which the material is supplied being situated between them. West Chop affords an instance of this. Its wasted cliffs have contributed to build up the "Hedge Fence" and "Squash Meadow" shoals on the flood, and the long ridge of the "Middle Ground" on the ebb. In bringing forward these particular shoals, however, it is not my purpose to attempt to account for the origin of the materials of all the shoals, but to show, what these cases are especially suited to do, their dependence on the currents.

Although the interior structure of the shoals is not accessible to examination, yet there is every reason to believe, in arguing by analogy from the beaches, cliffs, and hooks, that the sand composing them is deposited in layers, or strata. This is, in fact, the universal law of aqueous deposit. If the views concerning the formation of the shoals here presented be correct, they must have grown up gradually, and a time can be referred to when they did not exist. The rate of their accumulation would depend

upon the quantity of matter transported by the currents, and this again upon the degradation of the land.

The question is often asked, whether the presence of sandy materials in the water is discernible. I do not know how I can answer this question better than by repeating a circumstance related to me by our distinguished fellow-citizen, Mr. T. H. Perkins. About sixty years since he was approaching the coast of New England on his return from the West Indies. By the sudden and unexpected decrease in the depth of water, the vessel was discovered to be in dangerous proximity to the Nantucket South Shoals. The weather was stormy, but the captain found it necessary to carry sail to return again into deep water, and by doing so kept the decks of the vessel washed by the sea. In the morning the decks were covered with the sand which had been lodged there by the waves. The extent to which this part of the ocean is freighted with sand is no doubt always varying, but it may be fairly presumed that a large amount is furnished by every violent storm.

There is no satisfactory means of ascertaining what changes the present shoals have recently undergone. These are probably not important, though undoubtedly increasing. The causes that have produced them, the shoals themselves, and the general form of the shores, have, according to all authentic information, remained in a great measure the same during the historical period of the country.

One quality of the shoals which deserves special notice is their firm and compact structure. That this is not to be attributed to the superincumbent pressure of the water only is shown by the softness of the muddy bottom of the ocean, at the depth of a thousand fathoms. The water permeates so freely through the fine matter of which this is composed, that the upper part of the bottom is partially suspended in it, and thus the water, in resisting, shares the pressure from above. The hardness of the shoals, therefore, must be accounted for partly by the difference of the material, which, being much coarser, is better suited to form a solid structure in the water, and partly, perhaps chiefly, to the beating of the waves, which, hammering with unceasing industry upon their outside, drives the particles of sand closely together, and gives to the whole mass compactness and solidity.

Section II. — *Upon Hooks, Bay-Deposits, Bars, Beaches, &c.*

Shoals are the result of the constructive action of the tides beneath the surface. They do not appear above it on account of their exposed and disconnected situations, and the constant destructive action of the waves upon their summits.

There is another mode of constructive action, which, being finally exhibited partly above water, can be more easily traced in its progress, and which at the same time enables us to form an approximate idea of the rate of increase of the shoals. This mode is founded upon an action of the tidal currents which may be thus explained. A tidal current freighted with suspended matter, and eddying round a bold point, is interrupted and changed in its course by the projecting tongue or prominence at which it turns, and will leave there constantly a part of its burden, this prominence serving as a nucleus to a shoal or bar joined to the land, in the same manner as the inequalities of the bottom to the insulated shoal at sea. The subsequent gradual elevation of the shoal above the water is due to the influence of the winds.

It will be seen by looking at a map of the coast of the United States from the highlands of Navesink to the extremity of Cape Cod, that one normal form is constantly repeated. It is that of a projecting point lying in a generally north and south direction, and inclosing a bay of greater or less extent. That point on the New England coast called Cape Cod being the best known, I will refer to it as the type of this formation, which is repeated in the Great Point of Nantucket, in Cape Poge (Martha's Vineyard), and in Sandy Hook (New York harbour). There are also numerous small points, precisely similar in outline and relation to the local current, to be found in the harbours of this part of the coast. The tide passing along the outer shores, against which it presses with accumulated force, eddies around the extremity of the point, and expands in the inclosed space, where its velocity is lessened by diffusion.

Cape Cod is so large that it can only be examined as a whole on the map; but the small points, in the formation of which the principle is equally illustrated, are easily comprehended in a single view, while something can generally be learned of the rate of their formation from the residents in their neighbourhood.

As the original settlers of New York brought with them from their native alluvial shores the name which they transferred from the *Hoek von Holland* to the sea boundary of New York Bay, and as this name is literally significant of this very common form of alluvial deposit, I adopt the title as a generic term.

The tidal current, as has been said, after passing one of these points, falls into eddies on the inside. These eddies are favorable to an accumulation of the suspended matter, and may also be supposed to control its form. This mode of accumulation is a familiar one to engineers. In the rivers Aar and Rhone, walls projecting into the current are built expressly to obtain a new soil by creating eddies, the sedimentary matter being collected in large quantities by these eddies in one place. It is also understood and practised by our own engineers. At sea-walls and breakwaters the same effect is observed;

and it is a curious illustration of it that lobsters are now found at the breakwater in Delaware Bay, where none existed before, the eddying tides having in the few years that have elapsed since its construction deposited a material suited to their support.* That such deposits are partly above and partly below the water does not impair the efficiency of the cause by which they are produced. They are seen both above and below in the sandy formations of the New England coast, the submerged and exposed positions being continuous and forming a link between islands and shoals.

To return to the general statement: the currents, being interrupted in their course in passing prominent points, are easily deprived of their freights by any unevenness in the ground over which they move. This is so common, that, at every point and headland around which the tides turn, there is a shoal of greater or less extent joined to the land, and making a continuation of the beach. When the site is liable to the destructive violence of storms, the shoal will be small, shifting, and irregular. In the case of those points and capes already cited, which inclose bays, a protection is afforded to the eddies themselves and to the deposits made by them, that leads to certain and continuous increase.

Other circumstances may combine to produce the most favorable conditions under which the hook deposit can be made. If a current freighted with suspended matter has passed in its course over a bottom of regular and unbroken slope, it will, on reaching the point, have parted with but little of its burden. But the current, released from the restraint of the shore against which it presses, commences to turn inward at the place where the eddies created by the point arise, and then the most advantageous conditions of construction will coöperate, and the result will be a tongue or spit of curvilinear shape; that is, a perfect *hook*. This is the manner in which those bays or bights, more or less protected, which are seen on the inner side of each one of the sandy capes, are formed. The accumulation of material is in some cases so rapid as to be easily estimated from time to time. The hook, lengthened by successive additions, and brought to the surface by the tidal deposit, owes its gradual elevation above the water to the action of the winds. They transport materials from the opposite shores, and also drive up the sand that is left dry by the receding tide. These secondary points are sheltered from the destructive action of the waves by their primaries, and on the inner side of the former the protection is still more secure.

The new point of the hook gives rise to its own eddies, the effect of which is finally

* The process of "warping," as practised on the banks of the Humber, exhibits the working in a similar manner of this principle of deposit. — See Mr. Colman's *Agricultural Report*, Part VI.

to deposit on the inside, and near the extremity, a level plateau or flat of sand, as might be expected from the sluggish character of the derivative undulations, which here will have nearly reached a state of quiescence.

If the cape projects far into the sea, like Cape Cod, and incloses a deep bay, a large body of the current which turns to enter the bay at its extremity will pass the first hook and carry the flood towards the lower shores, and thus a new hook may be formed. But as it will not often happen that the circumstances in the second case are the same as those in the first, so the two constructions will differ in outline. One will be complete, like the Bay of Provincetown, and the other a shoal or bank interspersed with islands, like the second formation at Wellfleet Bay. Each one of the capes, Sandy Hook, Cape Poge, Great Point, and Cape Cod, are illustrations, more or less complete, of the hook structure.

We know something of the gradual growth of two of them from early surveys. It appears from a survey made in 1778, that at that date the northern limit of the point of Sandy Hook was about fifteen hundred feet from the old stone light-house. It has since then extended more than three thousand feet to the north and east. In 1778 the main ship-channel ran much nearer the light-house. But at the time of the discovery and settlement we must carry the extreme limit much farther south, bringing it nearer to Horseshoe Bay, where the form from which the name is derived would have been more exactly preserved. Since the preceding date we are able to trace, by surveys made from time to time, the manner and amount of alteration. The point has advanced to the north, spreading out to the east, and losing somewhat of its hook form, owing, no doubt, to the effect of an interruption to the tidal current on the outside, causing there a local excess in the deposit.

Plate III. exhibits the changes in Sandy Hook between 1778 and 1844. Plate II. is a copy of a chart of Cape Cod, by Des Barres, in 1764, from the library of the University at Cambridge. The inner part of the hook is there represented as a shoal. A still more surprising example of increase occurs in the belt called Nausett Beach, which incloses the harbour of Chatham. Captain Franklin Nickerson of Chatham informs me that when he first went to sea, twenty years ago, the common channel-way into Chatham harbour was two miles north of the present opening. The beach-grass is now growing on the site of the old channel. His father, he adds, who died about one year since, remembered when the channel-way was still farther north. The present inclosed basin was then an open harbour, and the inclosure has been made by the gradual extension of the belt to the south.

Great Point (Nantucket) furnishes a striking instance of external deposit. A long

shoal joined to the point extends four miles from the land in an east-northeast direction. An extraordinary supply of the material is brought to this spot by the tides, the first half of the ebb of the Sound conflicting hereabouts with the last half of the flood from the northern shore, and creating lower down a case of what seamen call "tide and half-tide." This shoal is indebted both to the flood and ebb tides for its great extent.

When similar deposits occur at capes and headlands belonging to an earlier geological period, they may come finally to protect the cliffs against further abrasion. Cape Poge is so protected, but West Chop, having no such defence, is, as has been already mentioned, constantly wearing away. It sometimes happens that the continued additions to the extremity of a hook unite it at last to the mainland. A sheet of water is then inclosed, making a lake or pond, breached by heavy gales, which may still have an occasional communication with the sea. Examples of this pond inclosure are common in all that part of the New England coast subject to alluvial deposit. The water in them will in the course of time become fresh, and as the sand continues to be heaped up on the outside of the separating belt (upon which dunes also will rise), their depth often exceeds that of the neighbouring sea. Mr. Lyell speaks of similar formations on the coast of Norfolk, near Yarmouth. Upon the island of Chappaquiddick, adjoining Martha's Vineyard, the people are now employed in converting one of these inclosures into a herring-pond; it is but a very few years ago that it was open to the sea, and has since been made fresh by rain and snow. Opposite to Cape Poge there is another pond nearly closed up, and one individual has undertaken during the last year to complete the work of nature by artificial means, for the same purpose.* This explanation of the manner in which a sheet of water may gradually, and without violence, be changed from salt to brackish, and from brackish to fresh, has, as will be shown hereafter, a peculiar interest in fossil geology.

The *hook deposit* is one of peculiar importance, on account of its form and of its relation to the bay it shelters. It is, however, of inferior importance in its amount either to the *bay deposit* or the *sound deposit*, both which are due to those principles of action of the tidal undulations which are briefly described as follows. The form assumed

* The lake of Stennis in the Orkney Islands "has been actually converted, within a very recent period, whether by elevation of the land or other cause, from a salt-water loch into a fresh-water and marshy tract." — Murchison, *Geology in Russia*, &c., p. 302. Is not this result produced in the manner described in the text? Dr. S. Cabot has stated, in a communication to the Natural History Society of Boston, that there is a pond of water six miles in circuit, called Great Pond, now perfectly fresh, on the eastern end of Long Island, which, thirty years ago, within the remembrance of many living people, was a harbour of refuge for small vessels. This is an authentic case of current action.

by the tide wave upon entering a bay is such, that but a comparatively small part of the body of water brought by the flood impinges upon the point or hook.

The current is carried towards the bottom and sides of the bay, and loses its velocity by degrees as it meets the resistance of the shores. The quiet condition thus produced is the one in which the water drops its burden with facility, and these deposits, to which I have given the name of *bay deposits*, are very large, speaking always comparatively, and follow strictly the contour of the earlier geological structure. In bays of every dimension there will be more or less conflict of the tidal streams, arising from their approaching each other at last from different sides of the bay. This creates an eddying action, which is also conducive to the increase of the deposit, and may perhaps give it a peculiar outline. Besides the formation at the bottom of every large bay, there will be on the inside of every hook a miniature bay also, in which the same conditions of the tidal current are repeated.

This *bay deposit*, then, is generally a skirt of shoal ground, continuous with the beach, and running off some distance under the water, where it is called a bank or shoal. On the inside of the hook, as is seen in the section of Edgartown harbour (Plate II.), the shoal part may be kept quite distinct from the shore by the play of the currents around it, and appear very similar to the isolated ridges formed in the exposed sea. In harbours (which, indeed, are specifically bays) this alluvial structure is never wanting. But in a region of sand the harbours that are found at the bottom of bays owe their existence, in a greater or less degree, to the alluvial deposit. The tidal current after striking the land will follow along its bend, and eddy around any projections that may interrupt its course, depositing a portion of its burden at every tide. The result will be the formation of a hook inclosing a harbour.

The harbour of Barnstable, at the bottom of the bay of Cape Cod, and the harbour of Nantucket, are both examples of this mode of action. The relation of the small hook to the harbour and its deposits is precisely the same as that of the large hook to the bay. The same forms, proportions, circumstances, and positions of deposit, and the same dependence on the local currents, are observed in each case.

These little hooks and their appendages are particularly interesting as a study. Living testimony is frequently obtained concerning their progress, and it is not impossible that an *era of hooks* may hereafter be added to the eras of dunes and deltas. Beach Point (Plate II.) is a beautiful specimen of the small hook, as Cape Cod itself is of the large hook. These two hooks are perfect in form; Great Point and Sandy Hook, on the other hand, are imperfect, the deposit on the outside being so great in the two last as to prevent the full effect of the eddying in giving the curved shape to the inner point or tongue.

Where there is a harbour at the bottom of the bay, as at Nantucket, Edgartown, and New York (the bight included between the Jersey shore and Long Island being considered as a bay with regard to the ocean), a part of the *bay deposit* takes the form of a bar across their entrance. The depth of water on the bar will correspond to the character of the harbour; so, also, will the depth and breadth and directness of the channels, these last being simply the passages kept open by the great body of the water that advances and retires with every successive flood and ebb. If the capacity of the harbour is small, as in the case of Nantucket, the bars will in some places rise near the surface, and the drains or channels will be contracted and narrow, their direction being controlled by the position of the shoals that accumulate near the mouth of the harbour.

If, as at Edgartown, there is a double communication with the sea, and a narrow channel that confines the water and gives rapidity to the current, then a greater depth will be preserved over the bar. And finally, if, as is the case at New York, there is a bay of large capacity, a double communication with the sea, and rivers emptying into the harbour, the depth of the channel over the bar must always be considerable. But the width of the entrance, as well as the capacity of the harbour and the action of rivers, will have a controlling influence upon this depth.

Let us pass for a moment from the harbours and inclosed basins of the North to the peculiar formations of the Southern coast. In Cape Cod, Great Point, Sandy Hook, &c., are exemplified the construction of the external points which shut off from the encroachments of the sea the large bays, under the protection of which are formed the smaller hooks and belts; and these last, as has been seen, may, and finally do, inclose ponds and create harbours. On the southern coast, similar phenomena occur on a large scale, in which the various principles already laid down are brought into play.

There are low borders of sand, forming for many miles the ocean boundary of the Carolinas and Georgia, inclosing lagoons of considerable space and depth, into which the rivers of the continent are discharged. A glance at the map will suffice to perceive the number and peculiarities of these formations.

There is one peculiarity of these inlets, which is, that they have a communication with the sea that is never destroyed, though its place may be changed. In this respect they differ from those in the Vineyard and Nantucket Sounds, which are eventually turned into ponds. Their characteristic feature, however, is, that they are the receptacles of one or more rivers, and that the capacity of each inlet appears to be proportionate to the number and size of the rivers emptying into it. This fact suggests the explanation of their mode of construction and actual condition.

In describing the Northern basins, notice was taken of the manner in which the cur-

rent performs the circuit of a bay, and in which it operates in building up the belt or outer border of the pond or harbour, after the style of a hook. That part of the tidal current which enters the lagoon, and revolves around its inner limit, not only assists this operation, but probably determines the place of the belt, and in some degree its form. Its place must be that of the confluence or meeting of the internal and external currents. When these lagoons are in the process of building up, a ripple upon the extremity of the belt, and beyond it in the line of its direction, indicates the seat of conflict between these two opposing forces. Now, in the case of the great lagoons of the Southern coast, this conflict derives a more distinct and permanent character from the currents of the rivers. There is a more powerful and complete action on the inside, arising from the coöperation of the tidal and river currents, the latter acquiring additional strength on the ebb from their being checked by the flood. The opening to the sea is preserved by the rivers that demand an outlet for their discharge, assisted by the flux and reflux of the tide. Across these openings lie bars of sand, formed, as has been said, by the deposits of the ocean tides, and not by the river deposits, which are wholly dissimilar in mineralogical composition.* The depth of water upon the bar will depend upon the size of the rivers, the capacity of the lagoons, and the rapidity of the tidal or ocean currents. Therefore, under favorable circumstances, the bar might, in the case of the Southern lagoons, as of the Northern ponds, rise to the surface, and, by completing the belt, break off the communication with the sea. The streams would discharge themselves into a lagoon thus inclosed as into a lake, and change them from salt to fresh water. Finally, the lagoon might be filled up by the river deposits, and a soil be accumulated suitable for tillage, even below the surface of the sea. Mr. Lyell's similar cases may be again referred to. (*Principles of Geology.*)

By these successive changes a home is created for animals of salt, brackish, and fresh water, in the same spot, where their remains may be found buried together; as they are now in the tertiary basins of Paris and London. The principle of confluence is illustrated wherever two moving streams of water meet, whether they belong to the ocean or to an inland sea, to tides or to rivers, or to both combined.

An instance of an imperfect lagoon formation, of classical celebrity, is that of Venice. The *lidi* are belts resulting from the confluence of the gulf and river waters. At the meeting of the Rhone and Arve a similar deposit in ridges is formed. In the beds of the small rivers that empty into the harbour of Boston the same results are produced, though here, of course, the influence of the tidal currents predominates. The shoals

* Professor H. D. Rogers has shown that these formations are caused by the meeting of the rivers with an external current. But he considers the Gulf Stream as the external current.

in our great estuaries, the Delaware and Chesapeake Bays, must be attributed to the confluent action of the tides.

The normal currents of the ocean may, however, take the place of the tidal currents, and exhibit the same effects. The constant current flowing into the Mediterranean Sea may be cited as a striking example. At the Rock of Gibraltar this current divides into two branches, one of which enters the Bay of Gibraltar, while the other passes to the eastward of the Rock; and the conflicting action of these two streams has built up the long and narrow ridge of sand, known by the name of the Neutral Ground, that unites the fortress to the Spanish peninsula. The large bank to the eastward of this ridge is an instance of *bay deposit.* In the Nehrungen of the Baltic, the external current is probably one that is caused by the prevailing winds. I have no doubt that these formations are to be accounted for in the same manner as all similar phenomena, but am not sufficiently well informed concerning the currents of the Baltic to speak of them in detail. Bars or belts of the same kind are found at the mouths of the rivers emptying into Lake Superior, and on the south shore they are so long that the river stream runs parallel to the land for some distance. These belts follow a constant direction, different on different sides of the lake, determined, no doubt, by the currents caused by the prevailing winds and by changes in the atmospheric pressure.

It follows from what has been said, that there are three distinct conditions under which the formation of belts and lagoons may take place. They may be the product of tides only, of which the currents act internally and externally, as in the ponds and small harbours, or partially inclosed basins, of Nantucket and Martha's Vineyard. They will occur on a much larger scale where the tidal action is assisted by rivers, as in the sounds and inlets of the Southern coast. And finally, the absence of a regular tide-stream may be supplied by a normal current, as at Gibraltar and in the Baltic. In all cases the direction of the belts is closely allied to that of the coast, being in general a little convex towards that quarter from which the external current approaches. When the tide is small, and the river rapid and loaded with matter, there is a strong tendency to fill up the lagoons and transform them into swamps. Large and muddy rivers penetrate beyond the sea-border and build up that form of deposit called deltas. The deltas, accordingly, are never surrounded by belts, like lagoons; and as these belts are produced by external currents, it follows that there can be no strong tidal or uniform ocean current where there is a delta. At the mouths of all those rivers most distinguished for their deltas, as the Mississippi, the Nile, the Po, the Rhone, and the Orinoco, there is little or no tide.

While, on the other hand, there are tides of a marked and decided character at the

mouths of other rivers equally strong and muddy in their currents, and magnificent in their dimensions, but having no delta deposits; as the Canton, the Guayaquil, the Amazon,* the Paraguay and others emptying into the Rio de la Plata, the rivers of Western Europe, and all the rivers on the eastern coast of North America, north of Florida.

Not only are deltas wanting where there are strong tides, but the mouths of the rivers affected by the tidal currents branch out into wide bays or estuaries filled with shoals composed of materials brought by the ocean (in our country quartzose sand), while the greater part of the river matter is carried off through the channels leading into the sea, owing to its lightness, and to the rapidity of the reflux caused by the retention of the river streams during the flood tide.

The conclusion, then, is drawn from these views of constructive action, that tides and delta deposits are incompatible with each other; that where there is a regular tidal or normal current of any consequence there can be no delta formed, and that such a current will always be a characteristic feature of those wide bays and river outlets where deltas do not exist. This fact of the absence of deltas where there are regular tides is distinctly stated by M. de la Bêche in his "Manual," who accounts for the apparent exception in the case of the River Ganges by remarking that the formation of the delta occurs in the rainy season, when the outward flow of the river is constant, overcoming the current of the flood tide, and keeping the water fresh for many miles at sea.

The most common and the best known of all the forms of ocean deposit remains to be noticed; that is, *beaches.* This term is applied indifferently to the borders of seas and lakes composed of loose materials, whatever that material may be. Where there is tide, it defines particularly the space included between low water and the highest reach of the tides. Beaches of sand line the whole coast of the United States, from Florida to the northern extremity of Cape Cod, sand being the material of which this part of our coast is exclusively composed. And here every variety of form and condition of beach is to be met with. If the shores are washed away by the destructive action of the waves, and its materials taken off by the currents, the beach marks the present limit of alteration. This is the case at the southeast part of Martha's Vineyard, where one mile in breadth of beach has disappeared in fifty years.

* The effect of the equatorial current (passing Cape St. Roque) is to take off to the north and west the solid matter brought down by the Amazon, and deposit it along the shore of French Guiana, or in the adjacent sea, which it has made shallow to the distance of several leagues from this coast. I have not overlooked this, and the remarkable character of the tides of the Amazon, nor the irregularities resulting from the conflict of the tidal and equatorial currents.

If, on the contrary, the shore is gaining, the beach shows the extent of the constructive process. The growth of Nausett Beach, already cited, is an example.

In some places the changes are irregular, as at Siasconsett, the southeast part of Nantucket. There is now but a narrow strip of beach between the cliff and the sea, where, between 1778 and 1792, the beach spread so much that the fishermen dried their fish upon it. The changes both of gain and loss are reported to have been gradual, and were no doubt connected with corresponding changes elsewhere.

The plastic power of water over so impressible a material gives to all sand beaches a general resemblance. It is impossible, therefore, to distinguish between those that are the remains of former shores, and those that are constantly increasing, without a knowledge of local facts and circumstances, such as may be frequently obtained from the neighbouring inhabitants. When *hooks* are united to the mainland, they become beaches. The same term is given to those necks of loose material which join islands with each other, or with the mainland, and which result from the confluence of two currents approaching from opposite directions. The beach of Nahant is built up in this manner, by the meeting of the two branches of the flood tide, one entering to the north and the other to the south of Nahant Head, at which the stream of the flood is divided. The "Neutral Ground" at Gibraltar has been already mentioned. The effect of this mode of construction is to change the geographical character of the place at which it occurs, by converting two or more islands into one, or an island into a promontory.

According to the principles laid down in this memoir, beaches should be found wherever there is a tidal or normal current. And it is so. Even on rocky coasts, where the tides are very rapid, the ocean deposits are made at the bottom of bays and in the indentations of the shores, the tidal currents losing in these situations their velocity, and turning easily into eddies. Phillips's Beach and Chelsea Beach are examples of this kind of bay deposit; but the rapidity of the currents and the exposure to the sea have prevented the beach formation on the projecting points of rock which inclose these bays, except in very sheltered spots.

Beaches are constantly undergoing changes, and these changes are likely to be extensive and important in proportion to the abundance of the material. They have always attracted much attention, especially where, as in Holland, the alluvial formations have exercised a real and permanent influence upon the public economy. It is these changes alone that have been treated by the geologists, who, overrating their individual consequence, have lost sight of the fact that they are merely the present indications of the modes and periods of great operations which have produced much grander results. The destructive agency of the waves upon them has been carefully studied, but the principles of their formation appear to have been wholly overlooked.

The action of the waves upon beaches creates the ribbed surface, the curvilinear outline, and apparent stratification which they exhibit. The light sea-weed, carried to the highest reach of the tide, gathers about it and along its extent the sand that is transported, either by the water or the wind. The curved lines follow the natural form of the summit of the wave; and the ribbed surface is an alternation of small sand-ridges and pebbly hollows, attributable to the abrasion of the latter, rolling back in a heap with the receding motion of the wave.

But the most noted and interesting effect of waves is the ripple-mark, seen upon the beaches of lakes as well as of the sea. It is produced under water by that slight agitation of the surface from which it takes its name, and is most conspicuous, perhaps, in beaches of long and gentle slope. Shores of this description are common to lakes, where, accordingly, the ripple-mark is abundantly displayed.* But the beaches of the sea are very irregular and various in declivity in the region of tides, as might be expected from the deposits which it is their office to make; and the same portions of the shores are alternately covered and exposed as the tides flow and ebb. Ripple-marks, therefore, will not be distributed over the beaches of the sea as uniformly as over those of lakes. Being similar in both instances, they must be distinguished from each other in the earlier geological periods by geographical positions. The ripple-mark is visible on the surface of many sandstone deposits, and may be taken, according to Mr. Agassiz, as a guide for estimating the early action of the moon upon the earth's surface, by means of the tidal motions.

In many places the sea-beaches are covered with longitudinal ridges of coarse gravel, pebbles, and stones, rising sometimes to a considerable height, lying parallel to the course of the shore, and following its sinuosities. A very interesting example of this is presented in Chelsea Beach, in Boston harbour. The ridge begins at the entrance of the bay, where it attains the greatest height, and where the stones, unmixed with gravel or sand, are of the largest size. The height and the size of the stones diminish gradually towards the bottom of the bay, until the pile terminates in a small ridge of gravel and sand, without stones. This phenomenon results from the combined action of waves and currents. At the upper part of the beach, there are high cliffs of coarse drift, which are washed and undermined by the sea, and their debris is carried away by the tidal currents in the direction of the flood, that is, towards the upper part of the beach. During violent storms, to which the beach is exposed, the coarse materials are projected upon the shore

* As the memoir and chart of M. A. Guyot have made us intimately acquainted with the lake of Neufchatel, I will adduce the southern shore of that lake as an obvious example.

by the waves beyond the reach of common tides, and, there heaped up, they form a natural sea-wall defending a tract of meadow land from the encroachments of the water. The structure of the wall on the land side affords a striking evidence of the projectile force of the waves. Owing to some causes that give them a greater violence in certain directions, they have so crowded up the stones that in some places they stand like abutments to the inside wall. But the part performed by the waves is merely to accumulate the materials in masses. It is the currents that transport the materials in their course, and decide their position; the best proof of this is the fact, that on the opposite side of the cliff there is no sea-wall, although there the action of the storm is equally felt. It might be objected, that the tidal currents are incapable of moving such heavy weights; but, besides the proofs afforded by the relative positions of the wall and cliffs, some facts will be brought forward hereafter which will remove this objection. It has been suggested, and I have no doubt correctly, that the kelp on the rocks assists the action of the currents by the large and buoyant surface it presents to their force. M. Elie de Beaumont has described the appearance of several similar formations; one, particularly, at Dieppe. In that instance, also, the source of the materials which form the sea-wall (*levée de galets*) is situated on that side from which the flood tide approaches. The tide rises to a greater height here than in Boston harbour, and the stones are transported by the current with such facility and in such abundance, that it has been found requisite to construct artificial walls, and contrive a plan for washing the channel by the river, in order to keep open the port.

It follows, therefore, that these sea-walls, though owing their actual form to the waves that keep the materials on the shore, owe equally their position to the currents, which, transporting the materials from the place where they have fallen into the sea, bring them where they will be subject to the action of the waves in storms.

When the beach is composed of light, silicious sand, easily transported by the wind, the phenomenon of *dunes* or *downs* appears. They are hills consisting altogether of light particles of sand, deposited by the tide, which, being exposed at low water, dries, and is blown up above the reach of the sea. The dune formations are immediately known by their peculiar figure. The top is smooth and rounded, sloping gently towards the quarter from which the sand comes, and steep and irregular on the opposite side. They are, however, too well known to require a particular description here, though they are so prominent a feature of a sandy region, that it would not be proper to pass them over entirely. M. de Beaumont has given the fullest details concerning their rise and progress, showing how they advance by successive steps into the interior, render sterile the soil which they invade, and overwhelm villages in their path. Sometimes, indeed,

they prove beneficial, by lining the inner border of the beach with a range of low hills that guard the land within from the inroads of the sea, or by fencing around a low cavity of water, which, being first converted into a swamp, becomes finally the only fertile ground of the region. But the surface of every alluvial soil is a dune formation. Capes, hooks, beaches, &c., owe their growth above water principally to this cause, and where the spot is favorably situated for such mode of accumulation the rate of increase can be satisfactorily estimated. Dunes, in common with deltas, accordingly have been employed as a *geological chronometer* for determining the periods of the actual alluvial formations. In Europe the phenomena of dunes are more extensively developed than in the United States. At Cape Cod, however, they exist in every variety and of the greatest size, and have formed with such rapidity, that the inhabitants of Provincetown, fearing to be buried in their progress, have planted great quantities of the beach-grass (*Calamagrostis arenaria*) on the northeast end of the cape for protection. This pioneer grass readily takes root, and lays the basis for vegetation.

One cause why the dune formation is less general in the United States is the absence of any great level country of sand, like Holland or the Landes of France. The chief reason is the hilly and unequal surface of that part of the coast in which the deposit is made. The sand is frequently deposited at the bottom of high cliffs, as at Martha's Vineyard and Nantucket, up which it is blown with such violence, in strong winds, that it is necessary to cover the face to secure it against injury. Upon the surface of the cliff, which it renders sterile by its constant additions, it is dispersed equally by the wind in level beds, following the form of the stratum on which it lies, and is not heaped up in the dune shape, as on the more level parts of the islands, and where the cliffs are low.

At Sankaty cliff, on the southeast part of Nantucket, there is a deposit of this loose sand, two and a half feet thick, covering the former soil. At the edge of the cliff, where it has been washed away, it is seen that this loose sand has covered swamps, which, having been drained by the destruction of the cliff, are converted into beds of dry peat. This deposit of sand must have begun after the wood, that once covered the island of Nantucket, was cut down. Its rate of increase, therefore, might be estimated. The wind deposit is distinguished from the water deposit by three peculiarities; — it follows the form of the stratum on which it lies, it is not stratified, and it contains no pebbles. At Cape Cod the ripple-mark made by the wind occurs frequently, and in several spots that are particularly liable to its action, the pressure of violent gales has produced a hardness of surface similar to that of the shoals, resulting from the action of the water.

SECTION III. — *Geographical Distribution.*

The preceding pages of this memoir have been devoted to a description of the various forms of ocean deposit, and to a statement of the mode of connection between those forms and the tidal currents from which they are derived. Hitherto I have confined my inquiries to the shores of the United States, and particularly to the coast of New England, because there the various results of constructive and destructive action were under immediate observation, the nature of the tidal currents was well known, and local information concerning recent changes has been most readily obtained. The next step is the application of the natural laws deducible from these investigations to similar formations on this continent and in other parts of the world. Before entering, however, into the subject of geographical distribution, it is necessary to lay down one principle of tidal deposit which has not yet been distinctly enunciated. It is this, that deposits upon the *ocean border* are only made by the current of the *flood* tide.

In the *sounds* and *bays*, the *ebb* tide may also leave its burden, since in its retreat it may not only meet with obstructions, but must press upon the land, in some parts, precisely as the advancing flood does upon the exterior coast. In a group like the Nantucket Shoals, the ebb, carrying with it the sand that has been loosened on the shore, and being hindered in its course by the inequalities of the bottom, must also contribute to build up the deposits. These cases are not alleged as exceptions to a law, but are stated as modifications merely, through which the action of the ebb is brought to resemble that of the flood. In general, as the deposit of the flood is made on the shore in the direction of its progress, so the deposit of the ebb is buried in the bosom of the ocean. The former furnishes the material for the alluvial deposit above water; the latter supplies the substances found in the depths of the sea.

It is not meant to say by this, that the action of the flood and ebb tides is reciprocal. On the contrary, the mode of operation of the flood is essentially cumulative. Its tendency, also, is to continually carry onward the deposit, in the course of its current, so that it performs the double office of increasing the collection at every successive tide, and of advancing from place to place the matter at its disposal. This double process is exemplified by the manner in which the materials of wrecks are conveyed along the shore in the direction of the flood at that place. I have previously said, that the course of the flood current on the outside of the island of Nantucket is from west to east on the south shore, and turning with the trend of the land from south to north on the east shore. A few years since, the British bark The Earl of Eglintoun was wrecked on the south side of the island of Nantucket, two miles east of the meridian of the town. Her

cargo consisted in part of coal, great quantities of which were carried round the island to the eastward and northward, and picked up on the inside of Great Point. The keeper of the light-house at Great Point supplied himself with fuel for the winter from this source. The brig Packet, of Providence, was also wrecked on the south side, opposite the town; and pieces and bales of duck and diaper were found along the beach to the north of Sankaty Head. The coal of a Philadelphia vessel, lost at the western end of the island a long time ago, was also carried round in the same way, and deposited at Great Point, the northern extremity of the island. In 1812, the English ship Queen, a prize to the privateer General Armstrong, was stranded, with her prize crew on board, on the south side, and, as it is supposed, at Miacomet Rip. Her cargo was strewed from the Rip, eastward and northward, to the end of Great Point. A chimney is now standing in the village of Siasconsett built of bricks from her cargo that were taken up in that vicinity, and some of the bricks were found about a year afterwards on the inside of Great Point, their edges rounded and smoothed by the action of the water. The bricks were known by their uncommon size. In none of these instances were any of the wrecked materials seen to the westward of the spot where they first struck the island, that is, in the direction of the ebb. This is well known to be universally the case, so that the wreckers never go to the westward, but always to the eastward, to search for floating articles. The fact is the more striking, that this course is opposed to the violent northeast gales, the principal cause of loss to shipping. For the preceding details I am indebted to Mr. Mitchell of Nantucket, the astronomer, to Mr. Rand, the collector of the port, and to Captain Rand, the father of the latter gentleman, a highly reputable and intelligent shipmaster.

But the characteristic action of the flood may be observed with even greater distinctness on the eastern shore of Cape Cod. There is a separation or split of the tides that takes place about six miles south of Nausett lights, and nine miles north of Chatham. The tide-wave divides in this vicinity, the current of the flood running north on that part of the cape shore which is north, and south on the southern side of the separation. At the place of separation the tide-currents appear to run towards and from the land, or, in the technical phrase, on and off shore. Now the materials of vessels that are wrecked to the southward of the seat of division of the tides are uniformly carried south, and are frequently found inside of Chatham (new) harbour, or of Monomoy Point; while, on the other hand, vessels that are wrecked so far northward as to be within the reach of the northern current of the flood have their effects scattered along the north shore, and, making occasionally the entire circuit of Cape Cod, are even deposited in Provincetown harbour. Here, as I am informed, this distinct action of the two currents of the flood

tide is so well understood, that those persons who search for the property of stranded vessels never go to the northward of the wreck when it lies to the south of the point of separation, or to the southward when it lies to the north of it. And in this latter case the movement is, as at Nantucket, opposite to the prevailing winds. The transportation of such heavy materials as coal and bricks has been mentioned. Mr. Small, the keeper of the light at Truro, from whom I have received much valuable information, communicated another curious instance of the power of the current in moving heavy articles. A brig of two hundred tons was stranded near Truro, and three weeks afterwards Mr. Small picked up her anchor, which had some ten fathoms of chain cable attached to it, about one and a half miles to the northward of the wreck. The anchor advanced, probably, by being turned over and over, the force of the water acting chiefly on the large surface of the stock; and the chain was dragged after. This illustrates the manner in which the kelp on the rocks at Chelsea Beach may be supposed to facilitate their transportation. Mr. Small also said, that, when articles float light upon the water, and offer a large body to the resistance of the wind, they may, during the violence of the storm, be carried against the current. During seven eighths of the time, to use the expression of Mr. Small, the waves break on the shore at Truro in a direction to the northward of west, the shore itself running north and south. This takes place in opposition to northerly winds. If these winds are exceedingly strong, they may for a short time overcome this prevailing tendency; but as soon as the strength of the gale abates, the waves resume their ordinary course. It is the same on the eastern shore of Sandy Hook and of Nantucket, as I have myself observed. As the flood tide runs in a northerly direction at each of these places, the idea is suggested that there is an intimate connection between the course of the current and the manner of approach of the waves to the beach; and if, upon further examination, this should prove to be the case, then the wave and current actions combine to produce the same effect, and we shall be less surprised at the transportation of heavy materials along the coast.

The constructive process of the flood is equally exhibited in the way in which the hooks, &c., are built up. They extend and increase always in the direction of the advancing current; as, for example, the Great Point of Nantucket gains constantly to the north, and the Point of Monomoy to the south, which are the directions of the flood currents at these two places respectively. And so with all the hooks, both great and small, of the northeastern coast, whether formed on the borders of the sea, or in inclosed bays and harbours.

To return to geographical distribution. The shores of the United States, from Florida to Maine, so far as alluvial deposits form the ocean border, exhibit similar features both

in outline and composition. In these respects there is a striking uniformity in the coast, while in the interior the geological diversities allow a wide range of dissimilarity. The keys and banks of the Florida coast, in which the deposit of sand is mixed with that of the coralline detritus, are to be considered on another occasion. Beginning, then, from the southern extremity of Georgia, and proceeding northward, there is a belt, of variable breadth and of loose material, the leading distinction of which is that it has been for a long time subjected to the action of water. This quality is so prominent as to create a uniformity of appearance independent of mineralogical composition, showing that it is the mechanical, rather than the chemical, properties which give the predominant character to these formations. A part of these alluvial deposits is formed and remains under water, as, for example, the Nantucket Shoals. But there are also, at a distance from the American continent, towards the northeast, very large subaqueous deposits, as George's, Newfoundland, and other banks, resembling the banks and shoals near the coast in structure and material, to which we are naturally led to apply the same laws of origin and formation. The idea of such a connection is not controverted by the distance apart, and apparently distinct separation, of the great banks; for the smaller banks and shoals near the land are divided by valleys of proportionate depth, having for their bottom mud, gravel, and large drift, teeming with animal life, in which the shoals themselves are wholly deficient.

Taking the whole of these sandy formations in one view, and considering them in relation to the continent, it will be remarked that a comparatively narrow and compact apex at the south spreads towards the north and east into a broadly diffused and unconnected series of deposits, and that throughout this extent all the minor varieties of geographical division are met with. But the greatest amount of the material is collected at the north and east, in which direction it seems to have been carried as to a place of final rest. A line traced with a free hand through this space will be the arc of a quadrant nearly, the abscissa being somewhat longer than the ordinate, and this upon examination proves to be the general course of the tide-wave on this continent. The effect of that undulation which rises in the Bay of Fundy will be noticed subsequently.

The progress of the great tidal wave of the Atlantic is from south to north; the cotidal lines, or lines representing the summit or ridge of the tide-wave, drawn between places on both sides of the ocean that have high water at the same time, being (speaking in general) at right angles to the meridians. These lines are curves, convex in the direction of their motion, in consequence of the retardation of their extremities by the shores of the continents. The effect of this retardation is to create those numerous tidal currents, and various conditions of rise and fall, of conflict and interference, which

constitute the *tides*, as they are spoken of in popular language, and known to the common observer. But the retarding influence will first be felt at the outer bank, or line of soundings, that marks the approach to the coast of the United States, and the result will be an early diversion of the tide-wave from its regular course, altogether independent of the local peculiarities occasioned by its subsequent collision with the diversities of the shore itself.

As the tide-wave, then, advances along the eastern border of this continent, it will be deflected to the east by the obstacles it encounters in its progress towards the coast of New England and the British possessions, until, passing the eastern limit of opposition at Newfoundland, its regular course is resumed. This statement is partially made in the first section of this memoir, where the conformation of the Nantucket Shoals is described, and their relation to the tidal currents defined. The Nantucket Shoals, being formed in the sea, have a closer affinity to the great banks than the hooks or bay-deposits, which are due to tidal currents that are specifically local. By enlarging the bounds of the reasoning applied to the former, we should expect to find those great sand deposits, George's, Sable Island, Banquereau, Green, Whale, and Newfoundland Banks, in the very positions they occupy, that is, in the path of the general tide-wave that washes the shores of the continent, modified as it is by the obstacles to its regular course.

It has already been assumed, that there is probably a nucleus which determines the precise locality of a subaqueous deposit, and that its amount and form depend upon the condition of the water as to motion or rest when it takes place. But I will also venture to suggest, that further investigations into the tidal currents of this part of the ocean may disclose a meeting of the tides at each of the two great banks of George and Newfoundland, perhaps from the confluence of the regular tide-wave of the Atlantic with the divergent wave from the American coast, the two waves belonging of course to different epochs. This view is supported by the motions of the tidal currents. They go entirely round the compass in every successive ebb and flood at both of these places. On George's Bank, according to the excellent survey of Captain Wilkes, the main body of the flood sets to the northward and westward, and changes from that to the eastward of north; and this change may be caused by a conflicting current from the coast. The prevailing opinion that there is a southerly and westerly current along the east and south coasts of Newfoundland indicates, in connection with the circular motion of the tidal currents on the Grand Bank, that a similar conflict may exist here also. On the southern coast of Nova Scotia, the establishments between Cape Sable and Cape Canso vary about one hour in time, being most early at the west. From this it appears that the tide-wave approaches this coast at right angles to its line of direction.

It is, moreover, to be observed, that George's Bank, the first in order from the coast, is situated remote from the land, and below the opening of the Bay of Fundy. In this free space the force of the current is weakened by diffusion. The banks lying to the southward of Nova Scotia and Newfoundland, where the velocity of the current is restored by the pressure of the tide upon the neighbouring coast, are comparatively long and narrow.

At the Grand Bank, the open ocean must again deprive the tidal currents of any character or force, except that derived from the obstructions of the bank itself, and there the diffusive deposit occurs for the last time, (except at the small Outer Bank, which is very indicative of a nucleus,) and on a much grander scale. Finally, the current that makes a circuit round the southeast extremity of the island terminates the bank of Newfoundland on the north in an elongated end, following somewhat the trend of the shore. Such at least is the form marked on the nautical charts.

If, again, after passing Cape Cod, we pursue the course of that undulation which supplies the coasts of Maine and the Bay of Fundy, we meet the two banks called Cashe's Ledge, and Jeffries' Bank, both of which are long and narrow. They lie in the region of rapid currents, which, as has been previously said, induce this form in constructive deposits.

Assuming the fact, that, in general, the strength of the current bears a direct ratio to the rise and fall of the tide,* it will be interesting to inquire into the range of the tide in those places where the ocean deposits exist. And from this inquiry it will appear, (not forgetting the importance to be attached to the inequalities of the bottom,) that the amount of the deposits everywhere holds a subordinate relation to the rise and fall of the tide.

In Delaware Bay, along the Jersey coast, at Sandy Hook, and in New York harbour, the range of the tide varies between five and six feet. In the Vineyard and Nantucket Sounds, where the shoal formations abound, it rises between two and four feet, being quite irregular in its motions, in its rise and fall, and in some places in its times, on account of the frequent interferences which, in these inland waters, arise from numerous communications with the sea. On the Nantucket Shoals the tides rise to the height of five feet.

At the southeast part of Cape Cod, that is, the north part of Nantucket Sound, the range of the tide is very small, and, as I have already noticed, a convergence takes place

* This statement is made without losing sight of the effect of retardation and accumulation at headlands, points, shoals, &c., which is to produce great rapidity of current in those places, even where the range of the tide is small.

here of the tidal streams coming in opposite directions from Nausett Beach towards the south, and from the island of Nantucket towards the north. This convergence is immediately suggested by the fact, that, if a vessel grounds on the *south* side of one of the shoals in this vicinity whilst the tide is running ebb, she will begin to float on the last quarter of the ebb current. The shoal formations are numerous and extensive here, and, according to the information given me by the inhabitants, accumulate rapidly in favorable situations. Dry Shoal is a name given to one of them that has appeared above water within a few years in a protected part of the bay formed by Monomoy Beach, and opposite to the opening into Chatham "New Harbour." There are no shoals on the Cape Cod shore north of Nausett, though some bars are deposited at the point of the cape. At Cape Cod the tide rises ten feet. On the coast of Maine the tide rises from ten to eighteen feet, being greatest at the north; and in the Bay of Fundy it rises to the extraordinary height of sixty feet. On the coast of Maine and in the Bay of Fundy there are no shoals.

On the Atlantic south coast of Nova Scotia, which is lined with banks at some distance from it, the average range of the tide descends again to eight and six feet. Upon George's Bank the tide rises seven feet, and though but little is known of the tides of the open ocean, yet it may be safely assumed that at Newfoundland Bank the range is not great. In all the cases cited above, there is an observable proportion between the tides and the aqueous deposits, the amount of the latter being more, as the height, &c., of the former is less.

This reasoning does not imply that shoals should be found wherever the character of the tide is suitable for their formation. A proportion must also exist between the amount of deposit and the quantity of loose material; and it is perhaps to the deficiency of the latter that we are to ascribe the absence of shoals on certain parts of the western coasts of this continent.

Passing from the shores of America to those of Europe, we there find deposits of sand of remarkable extent, giving the same character to navigation as here, and constituting, in one instance, the residence of a people distinguished in arts and commerce, whose national economy derives a peculiar stamp from the nature of the soil they inhabit. Holland is the most interesting, in many respects, of all similar formations. It is situated on the southeast corner of the German Ocean, where the tide-waves that enter through the Straits of Dover are met and repelled by those which, making the circuit of the British isles, return again from the north. This convergence of conflicting currents is the condition already specified as the one the most favorable to a large deposit. The narrowness of the English Channel, by creating rapid currents, forbids deposits there,

except in those small bights and bays where the water becomes still, or expends its force in eddies. But when, after passing the Channel, the sea expands, the circumstances are again suited to the deposition of its burden, especially on the side concave to its axis, or, in other words, having the bay form; which is the situs of the Netherlands and the peninsula of Jutland.

The convergence of the tide-waves in the North Sea and English Channel is a very conspicuous feature of this region. Professor Whewell, from whose valuable *Researches on the Tides* I have received much assistance, has endeavoured to "combine all the facts into a consistent scheme by dividing this ocean into two *rotatory* systems of tide-waves; one occupying the space from Norfolk and Holland to Norway, and the other the space between the Netherlands and England." On the coast of Jutland there is a vanishing point of the tide which he endeavours to explain by the motions of the former system.

Throughout this region there is a correspondence between the height of the tide on the one hand, and the form of the land and amount of the deposits on the other. The greatest range of the tide between Brest and Dunkirk varies from thirty to sixteen feet. But after passing the narrow limits of the Channel, it descends, in proceeding along the coast of the Netherlands, to nine, six, and three feet. Finally, on the north of Jutland, the tide ceases to rise altogether; a state of perfect uniformity is produced by the conflicting currents.

In this conflict of the tide-waves coming from the north with those advancing through the British Channel, by which the latter are forced over upon the eastern shore, retarded in their progress, and finally repelled; in these rotary systems or eddies upon a grand scale of the tidal currents; in the bay form of the shore; and in the gradually decreasing height of the tide taken as an exponent of its strength, we have a combination of all the circumstances most favorable to alluvial and subaqueous deposits. Accordingly, not only have the sandy regions of the Netherlands, raised above the water by atmospheric influences, been accumulated, but the North Sea also abounds in shoal formations of every description. This is the grand depot of the loose material on the eastern coast, to which it has been transported by successive degrees, and in which it has been confined by the double action of the tides. To apply in detail to the various forms of deposit, common here as well as on the American coast, the reasoning contained in the first and second sections of this memoir, would be, even if I could trust to my imperfect knowledge of the local currents to attempt it, merely to repeat what has been already said. But the object in this section is the development of general principles, and not the explanation of particular cases.

But I must allude in passing to two other instances of alluvial deposit, one on the

coast of Norfolk and Suffolk; the other, on the southern shores of Norway. The first of these instances occurs at the meeting of tides arriving in opposite directions along two different channels, and this meeting is pointed out by the crowding together of the co-tidal lines, or, in other words, by the rapid change in the tide-hours due to the impeded progress of the tide-wave. Between Yarmouth and Southwold, the least range of the tide is two or three feet, while the greatest range is only seven or eight feet. But at points on each side of these stations, and not far distant from them, the greatest range of the tide rises to twenty feet. (See Whewell's *Researches on the Tides*, Sixth Series.) The changes that have taken place on this part of the English coast have been described in detail by Sir Charles Lyell, and M. Beaumont. It is not necessary to repeat here what has been said concerning them, but it must be admitted that they support in a satisfactory manner the view that the amount and locality of alluvial deposits are in certain cases determined by the interference or convergence of opposing tide-waves, and dependent in a measure also upon the motion of the tidal currents, of which the average rise and fall of the tides may be taken as an exponent.

The subaqueous deposits, or banks, off Yarmouth result from the same causes. The alluvial formation in the Wash is an instance of *bay deposit.*

With regard to the sandy region on the southern coast of Norway, of which Christiansand is the principal depot, it is to be observed that Stavanger is a point of divergence, from which one portion of the divided tide-wave travels sluggishly along the south shore, until, at Christiansand, the greatest range of the tide is only one foot. It is a probable inference from the principles laid down, that the deposit in this region is owing to the conflict of the feeble tidal current corresponding to this tide-wave with the constant current that flows out of the Baltic.

This current always sets to the westward along the shore, but its force must be gradually overcome by the pressure of the tidal current, which becomes more sensible as it proceeds to the westward. It is further to be remarked, that the currents created by the winds on the southwest coast of Norway run much stronger to the south than they ever do to the north.

The Landes of France, at the bottom of the Bay of Biscay, is another region of sand too well known to geologists to need description. It is an instance of the *bay deposit* on a large scale, as Holland is of the *sound deposit.* It lies in the place to which the material should be carried by the tide, which, turning round Cape Ortegal, makes the circuit of a great bay. The original form of the bay, at the beginning of the present era, was deep and pointed towards the bottom, and thus particularly suited to create numerous interferences resulting in eddies, and in that state of rest in which the water readily drops its freight.

Here, again, the course of the tide-wave is favorable to an extreme accumulation. There is a point of divergence between Santander and Bilboa, and the undulation which passed on into the bottom of the bay must have been overtaken, and opposed on its turning to the north, by the succeeding tide-wave, particularly in the early epoch of this formation, before the bay was filled up as at present, and while the tide-wave would occupy a longer time in its transit. At Santander and Bilboa, the average height of the tide is nine or ten feet. I have no means of ascertaining what it is at the bottom of the bay.

The similarity in effect of the *normal* currents of the ocean, when they strike the land, to the currents of the tides, is displayed in the general as well as the local deposits. The deposit in the Mediterranean has been mentioned.

Another striking example occurs in the Gulf of Mexico. There is a current which, entering by Yucatan, makes a circuit of the coasts of Mexico, Texas, Louisiana, &c., and finally becomes a tributary to the Gulf Stream.

In the Bay of Campeachy there is a large bay deposit, and the shores of the Gulf on the west and north (interrupted only by the deltas of the Mississippi) are altogether alluvial, being composed of the same loose material as those of the Atlantic border of the United States. M. Elie de Beaumont has dwelt with some particularity upon the description of the Gulf coast.

But the western coast of Peru affords, perhaps, the most interesting illustration of the effect produced by the action of a constant ocean current. There is an antarctic current which strikes the western coast of South America to the northward of the island of Chiloe, and, pressing against the shores, follows their course up to the parallel of four and a half degrees south, or the southern entrance of the estuary of Guayaquil, when it turns off towards the Galapagos Islands. On the Peruvian coast there is a zone or belt of sand, two thousand miles in length, and varying in breadth from seven to fifty miles. The greater part of this sand is heaped up by gradual accumulation, according to the law of constant transport from place to place, at the northern part of Peru, the terminus of the connection between the current and the land. In this region it has created the desert of Pachira. The rise of the tides in the River Guayaquil is six feet, which has given birth to an estuary, the southern shore of which is sandy. This shore is the place of meeting (against the land) of the ocean and tidal currents.

As the form of the eastern coast of North America coincides with the general direction of the Gulf Stream, it may be suggested that we are to look to that as one of the causes to which this form is due. The effect of the Gulf Stream as a normal current of the ocean, where it actually impinges upon the extreme southern portion of the coast

of the United States, has been considered. The power it may exert in carrying forward the tidal undulation while it is passing through it, and thus in affecting the condition of the coast, is worthy of inquiry. But in this memoir the forms, localities, and amounts of the alluvial deposits have been attributed to the active influence of local currents; the same reasonings could not be applied to the Gulf Stream, which only touches the land in the beginning of its course. So far as the general course of the Gulf Stream is owing to the line of soundings on the coast, it must be regarded as a consequence, and not a cause, of the form of the bank against which it presses. It is well known, however, that farther north there is a counter current inside of the stream running in the opposite direction, and its superficial character shows that, here at least, its movement is independent of the form of the bottom. The direction of its current is in fact that of an eddy on a gigantic scale, and is caused, not so much by the form of the bottom at its origin, as by the constantly increasing resistance of water of a lower temperature; and perhaps it is in part to this resistance that we are to look for the origin of the inside counter currents at the north, which resemble those created by the land in retarding the tidal currents. The waters of the Gulf Stream are, moreover, too clear to admit the supposition, that they take any part in alluvial formations other than that already stated.

The question may also arise, whether the whole alluvial and subaqueous formations of this eastern coast of North America may not have been at one period united, and whether the channels that now separate them may not have been subsequently made by the draining of the continent, or some convulsive action of the sea. But the consideration of this view will be deferred until it is formally presented.

Section IV. — *Conclusion.*

Hitherto the *tides* have been regarded chiefly as an astronomical problem; but if the views brought forward in the preceding sections of this memoir are correct, they must hereafter be treated also as a strict geological problem, applicable to all ages of the earth's history.

It has been shown in the preceding pages that there are territories, more or less inhabited, which have been formed in historical times by the gradual accumulation of matter held in suspension, and carried by the waters of the sea; that this matter has been deposited chiefly in conformity with the laws of the tides; and therefore that the tides must have remained the same during the whole period of the deposit, their present courses and other conditions being due, in general, to the forms of the shores at the commencement of the actual epoch.

But the causes of the tides, and therefore the tides themselves, have always existed. We may ascend to an ancient geological period, when the regular progress of the tidal undulations was much less interrupted than now; still we must admit the existence of tidal currents so long as we conceive the interposition of shoals, islands, or continents in the path of those undulations. Theoretically speaking, then, we should expect to find a certain conformity between the oceanic deposits of all ages and the currents of the epochs in which they were made, which conformity should be the more apparent the nearer we come to the actual epoch. It has been pointed out that there exists a fixed relation on the part of the tidal currents to the *alluvial* deposits, in their structure, position, and amount; or, as the tidal currents depend on the form of the land, it may be said that on the south coast of New England this relation is maintained between the present deposits and the shores of the post-pliocene period. So distinct is this relation, that the character of the alluvial deposit on the borders and in the depths of the sea is readily determined when the direction and other circumstances of the local currents are known. This suggests a principle of conformation by means of which the geologists will be able to reason back from the forms of the earlier deposits to the currents of their respective periods.

It is the prevalent opinion among geologists that the most important and durable changes in the surface of the globe have been ushered in by epochs of convulsive disturbance. This is not the place to discuss the limits of these changes. It may be presumed that during these convulsions the operation of the tidal laws was overruled, or controlled. But since these laws are active and unchangeable, they must have struggled to regain their natural ascendency, to which they will have been restored in periods of quiet action. Accordingly the currents created by the tides are to be counted among the most effective of the natural agents at work throughout all periods of quiet action in giving their present form to the great continents; and thus the whole economy of the earth's condition appears to be as intimately connected with the regular movements of the ocean, depending upon astronomical influences, as with its occasional and tumultuous disturbances. This action of the tides, or, in other words, the influence in this manner of the moon upon the earth's surface, is a new application of the law of gravitation, which has been employed by the Author of the universe, not only in holding together the bodies of the system, but also in distributing the materials of which they are composed according to His plan of creation.

The *tidal theory* now introduced into geology does not assume the discovery of a new law, but indicates a new mode of operation of an established law. It conforms to that view to which all improvements in science seem to tend, — a simplification of the laws of creation.

Without designing to undertake any thing like a minute description of geological districts, I will proceed in a very brief and general manner to cite a few instances of the geological action of the tides in the past ages of the earth's history. The instances will be taken from the tertiary and subsequent periods, principally for the obvious reason that they have undergone fewer changes since the time of their deposition. The idea immediately suggests itself, that, if this theory of aqueous deposit be correct, we ought to find the alluvial, quaternary, and tertiary formations in close proximity to each other, particularly where those of an earlier period are so situated as to preclude the possibility of any great alteration in the transmission of the tide-waves during that long interval. Taking the first example from this country, it will be seen by a reference o Sir Charles Lyell's geological map of the United States, that the cretaceous, tertiary, and post-pliocene deposits lie along the borders of the coast, succeeding each other outwards in the order in which they are named. They appear to follow one another in regular course, according to the laws of tidal deposit, each period showing larger than that which precedes it, and which it overlies.

The post-pliocene, being outside of all, and accumulated on the shores of the Northern and Eastern States by the constant transporting power of the current of the flood, effected a gradual change in the progress of the tide-wave, diverting it more to the eastward. Long Island, and the islands on the southern coast of Massachusetts, all of which were the shoal formations of that period, contributed greatly towards this change. The locality of these islands was determined by the nucleus of a former period, and their form or outline must be ascribed to the action of tidal currents. In the case of Long Island,* the shoal commenced probably at the heights of Brooklyn, the highest part of the island, and was gradually built up towards the east. The deposit was at first assisted by the confluence of the tidal with the river currents; and afterwards by that of the tides of the Sound conflicting with those of the open sea, the former running at that time, as now, through the deep and rocky chasm of Hell-Gate.

The islands on the Massachusetts coast and the district of Cape Cod were constructed by a similar process, their forms also being due to the different directions and modes of action of the currents in that region. But as the eastern coast is the most exposed to the destructive action of the prevailing storms, its shores, being gradually acted upon and degraded as the continent was upheaved, now appear as precipitous cliffs, where the stratified deposits show to the greatest advantage.

* In the minute and able account of the geology of this island, particularly of the alluvial formations and their changes, by Professor Mather, the reader will find several cases in which this theory of the geological action of the tidal currents is applicable.

Below the stratified drift there may be seen at two points, Sankaty Head (Nantucket) and Truro (Cape Cod), a stratum of clay, which Mr. Desor and Mr. Edward C. Cabot regard as the eastern outcrop of a wide tertiary basin, extending below the islands of Nantucket and Martha's Vineyard, and forming the nuclei for the overlaying drift-beds when they were deposited in the condition of shoals.

There is some reason for assuming a similar superposition of strata of different ages in the great banks to the northeast of the continent. It is certainly not a matter of chance that there is no tertiary and so little stratified drift to be found north of Cape Cod. In order to account for their absence, we must admit that there has been formerly a far greater amount of dry land than now, which is not in accordance with the general features of the country; or we must conclude that in those periods the tidal current was, as it is now, too rapid to allow the formation of shoals along the coasts of Maine, &c., and that the materials held in suspension were consequently carried still further, and dropped in those great seats of deposit, George's, Newfoundland, and other banks in that vicinity. This assumption helps to explain both the extent of these banks and their height above the bottom of the ocean, which cannot without apparent difficulty be ascribed merely to the tidal deposit of the actual period. But as the quaternary deposits, being the last in order, have been accumulated on the northeast, so the alluvium, carried beyond them by the new course given to the tide-wave, is seen in the greatest quantities in the vast subaqueous deposits of the Nantucket shoals and banks, the great and little banks of George and Newfoundland, and those off the coast of Nova Scotia, before enumerated.

Passing from the coast to the interior, this theory of tidal action serves to explain the geological peculiarities of those great plains both of North and South America, the prairies and the pampas, which may be considered the deposits of gigantic bays during the state of subsidence of the continent.

On the continent of Europe and the British Islands, the primary rocks of Portugal and Spain, and the primary and secondary formations of the French and British coasts, have a general similarity of outline to the present shores. *Within these limits*, therefore, the transmission of the tide-waves has remained very nearly the same. Upon examining the geological map, a break is found to occur in these early formations, reaching from the western vale of the Lower Pyrenees to the entrance of the Gironde. This, which is the alluvial coast of the Bay of Biscay, noticed in the preceding section, is the external boundary of a vast basin of tertiary and drift deposits, the former being inside. Making a curve from Limoux towards Montpellier, the middle tertiary extends in a narrow belt between the chalk on one side and the transition series on the other, until it meets

the alluvial deposits of the Gulf of Lyons. Thus the matter deposited by the currents of the tides, acting in conformity with the principles here laid down, has become by subsequent upheaval the means of uniting the former island, but now peninsula, of Spain to the continent of Europe. This is an instance of bay deposit.

Another instance of bay deposit is the great tertiary basin of Paris, confined on the lower sides and to the west by the jurassic and cretaceous regions, and separated in part from the tertiary of Belgium by the upper chalk.

A third striking case of the bay deposit in the tertiary period is the clay basin of London, the limits of which are determined by the upper secondary, bounding it on all sides except at the entrance. The tertiary of Hampshire is a case of sound deposit, and that of Norfolk and Suffolk occurs (as has been said of the alluvium lying outside of it) precisely at the region of meeting of the tides coming from the Straits of Dover and the North Sea, where a convergence and retardation of the tide-waves creates the circumstances under which the sea parts easily with the matter held in suspension.

All the previous cases have been cited merely as examples. Having before me the magnificent geological maps of France, and the maps of other parts of Europe, it would be very easy to multiply the number of them; but these are sufficient for illustration.

An interesting application of this theory is suggested by Mr. Desor, as follows. Geologists have observed that there occur in the same geological horizon deposits differing entirely in mineralogical character and in fossil remains. Gressly, who with careful accuracy traced out the line of demarcation between such deposits in his *Observations sur le Jura Soleurois*,* and fully recognized their peculiarities, gave them a distinct classification, in which he included the muddy region (*facies vaseux*) and the shoal region (*facies de charriage*). If, adds Mr. Desor, the upheaval of this continent should affect the south coast of Massachusetts so as to expose the bottom of Cape Cod Bay or of Nantucket Sound, there would be seen in those places precisely the same varieties of formation and condition as in the tertiary of the Swiss valley. These geological peculiarities, then, are accounted for when we consider the latter as the sound and bay deposits of the tertiary period, and, this view being correct, it will be a future demand upon the attention of the geologist to endeavour to identify in similar cases all those varieties of form and conditions of deposit which are typified in the alluvial and subaqueous deposits of the actual epoch.

Professor A. Gray has called my attention to the manner in which this theory may be made to throw light upon the geographical distribution of certain plants. The dune

* Memoirs of the Helvetic Society of Science.

or alluvial flora of North Carolina is repeated, as he informs me, on the shores of New Jersey, of Long Island, and the southern and eastern coast of New England. Following the course of the tide-wave, these Southern plants are found at Plymouth (opposite Cape Cod), where there is a large bay deposit, and to the north of Cape Ann, in the bight formed by the projection of this cape, where also occurs another instance of bay deposit, at Ipswich, and Newburyport. Lastly, a few of these plants are found on the south coast of Nova Scotia. How far this reasoning may be thought to explain the existence of the same flora in the adjacent countries, situated on opposite sides of the same channel, and washed by tidal streams which, acting upon a system of rotation, have carried the same materials in succession to the shores of each, through the long ages of the past, is hereafter to be considered. A similar result will also be produced in two countries far remote from each other by the transmission of a tidal undulation which, leaving a bold and projecting coast, arrives, without intermediate interruption, at some distant point or island.

Having already dwelt longer than was intended upon this part of the subject, I will only make a hasty reference to the utility of this theory of the geological action of the tides in accounting for the great sand deserts, as it has been applied (in Sect. III.) to explain the Peruvian sand desert of Pachira.

The interposition of a continent (or chain of islands) occupying a great extent of latitude in the path of the elementary tide-waves, as is the case with Africa, may be supposed to offer the most favorable conditions for immense sand deposits exceeding all others in amount. Here the tidal currents would be employed, not only in distributing and collecting the detritus of the African mountains, but also in transporting a part of that of the Eastern continent and islands. The extent of the sand deserts, so characteristic of this part of the globe, is to be attributed mainly to the wide spaces between the higher grounds, or earlier formations, in which the various forms of deposit have been often repeated on a grand scale. These, however, and other geological details, are designedly left, on account of their number and diversity, to a future and not distant occasion.

But there is no point of view from which the geological action of the tides appears more interesting than in its connection with the geographical distribution of marine animals. It is well known to the zoölogist that the sea is the principal seat of animal life, and that it is near the land, and not in the distant depths of the ocean, that this life is displayed in the greatest amount and variety. It will be found upon inquiry that marine animal life is most abundant and most useful to man on the shoal formations. In this region are the great fishing stations, and, as fishes are predatory in their habits,

here also exist the smaller tribes that supply their food. It is only necessary to refer to George's and Newfoundland, Cashe's and Jeffries Banks, &c. Nearer the coast the smaller banks are resorted to habitually by fishermen, as the places most favorable to their pursuits. In all these shoal formations, however, there is a principle of distribution depending upon the relative depths of the water.

It has been ascertained by Mr. Agassiz, in his researches on the southern coast of Massachusetts and among the Nantucket South Shoals, that a depth varying from seven to twenty fathoms is, in this part of the open sea, most suitable to the existence of those classes of animals that either adhere to the materials of the bottom, like polypes, or that move always on the ground, not having the power to swim, as the radiata and worms. On the ridges or highest parts of the actual shoals no animals are found. They are marine deserts, in which no life, either animal or vegetable, can be supported.

In passing from the summit of one shoal through the intervening channel to the summit of another, the following facts have been repeatedly observed by Mr. Desor and myself.* The top of the shoal, which consists of fine sand, has always been found wholly destitute of the traces even of life. Upon descending a little, the dredge brings up from the side of the shoal, and near its base, large quantities of broken shells, which appear to cover the bottom in some places to a considerable depth. These shells are clean and water-worn, and have no polypes or animal remains attached to them. Still lower down, the freight of the dredge will consist of pebbly stones, rounded and smooth, and a few animals. The pebbles may have polypes (membranipora) on all parts of them, showing that they are liable to be moved by the agitations of the sea. From the lowest part of the channel or valley the dredge brings up stones of a larger size and more irregular shape, having rough and uneven surfaces, and covered on one side chiefly with polypes and barnacles, and, together with these stones, a great number of animals, such as echini, starfishes, worms, crabs, and numerous bivalves and univalves. The same succession will be repeated in the reverse order, on passing to the summit of the next shoal.

These facts may be thus explained. The shoals themselves are composed of materials not adapted for the support of life; and they rise so near the surface as to be subjected to the constant destructive action of the waves, which break upon them in all but the calmest weathers. Although their average height remains the same, yet the loose materials of which they are constructed are easily transposed, and must be occasionally increased and lessened by the alternate deposits of the tidal currents, and the destructive agitations of the sea in heavy storms. The shoals are, in short, in

* These facts were presented by Mr. Desor to the Scientific Convention recently held at Philadelphia.

a constant state of motion. The channels, on the other hand, are sheltered by the shoals, as well as defended from disturbance by their greater depth. This double protection secures a condition of permanent rest, requisite for the full development of marine animal life. The pebbles, higher up, notwithstanding that they are liable to be moved, appear to be sufficiently stable to become the base on which the ruder animals build, and the home for a few of the moving species. The dead and broken shells are to be included among those materials that are easily transported by the currents, for the collection of which the shoals serve as nuclei. In harbours and inclosed waters generally, animal life will exist in abundance at a less depth, because these positions are more protected by the land from the effects of the waves.

It is only with regard to the Nantucket Shoals that the depth varying from seven to twenty fathoms (from 42 to 120 feet) is specified as the most prolific. There is no intention of saying that these depths are universally the most abundant. Animal life is no doubt to be found elsewhere in similar quantities and diversities much farther below the surface. The greatest of these depths, however, is shallow compared with the abysses of the ocean, which must be wholly destitute of those classes that derive their sustenance from the bottom. By the help of the foregoing facts, we are able to account for the enormous display of marine fossils found in the earlier strata, and distributed throughout regions of great extent. The shallowness of the sea in those periods and at those places afforded the condition best suited to the fruitful development of animal life. And the changes that have led to the present inequalities of the bottom of the sea appear to have confined in a measure to the shoal formations of the actual period the homes and the support of that marine animal life which was formerly more widely diffused.

This, then, appears to be one of the grand results of the operation of the tidal laws, as disclosed in this paper. Throughout all periods of geology it has prepared the place suitable to marine animal life.

Another office performed by the tidal and normal currents of the sea has been to transport and diffuse, in great quantities, the loose materials of the ocean, and to increase the area of dry land by taking off and collecting together in plains the detritus of higher regions, filling up, in this manner, the empty spaces between steep and rugged boundaries, and giving form and body to the continents. Upon looking back to the early ages of geology, we can assign no date to the commencement of such operations other than that of the origin of the tidal currents; and these are coeval with the first appearance of land above the surface of the ocean. But as all these grand operations, by means of which the physical condition of the globe has been made to pass through its successive changes, are intimately connected with each other, and purposely ordered, and as the prevailing tendency of the present laws of tidal and oceanic current action

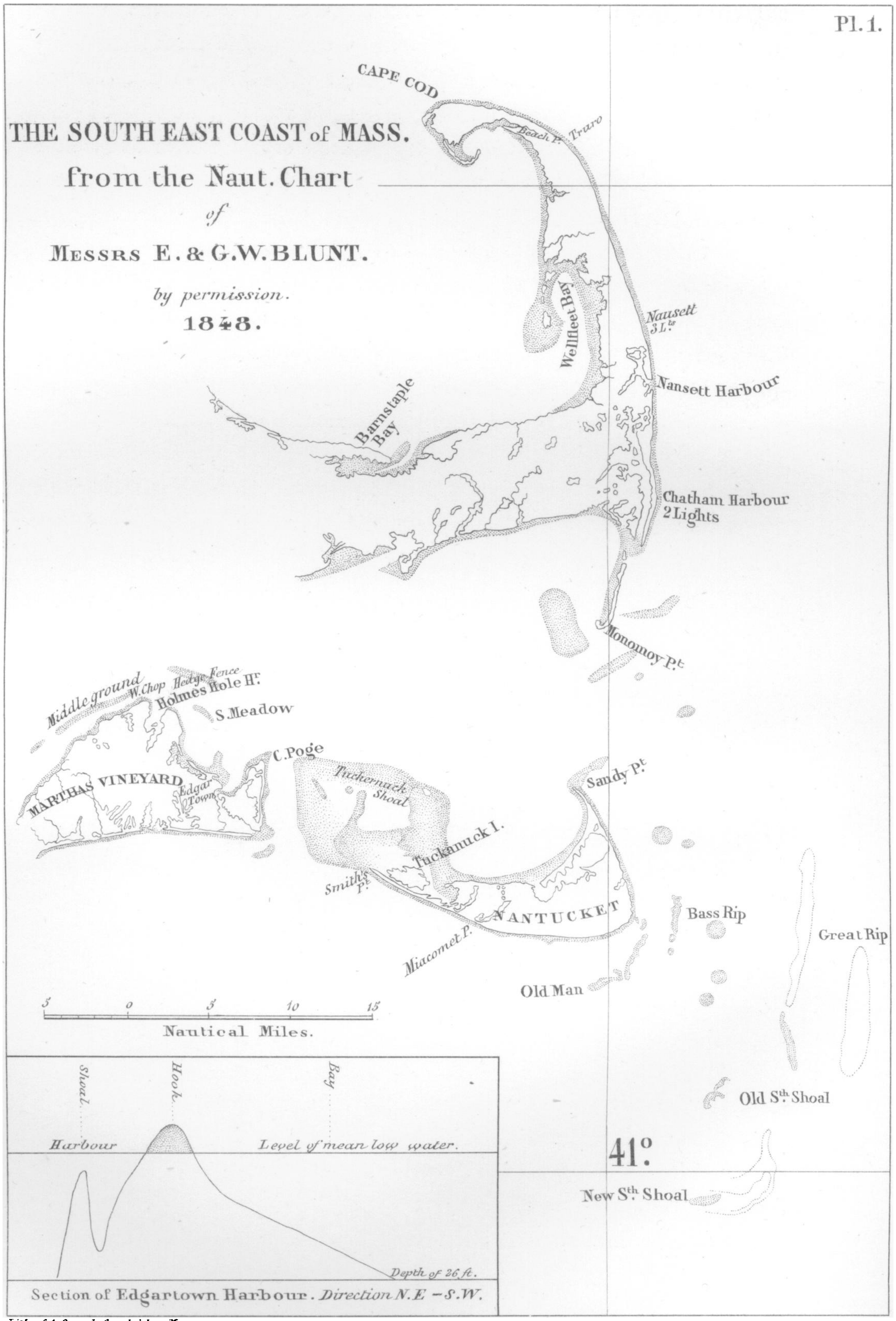
has been to increase the extent of land in the northern hemisphere, so an inquiry is naturally suggested into the relation between this theory of the geological action of the tides and that branch of physical geography which treats the progress of human civilization and development as dependent upon the material form and structure of those parts of the earth which have been successively inhabited by man.

And, finally, when we consider that it is those deposits which have been subjected to the influence and have followed the laws of tidal and current action that constitute man's most convenient dwelling-place, that are best fitted to provide the means of his support, and to facilitate intercommunication between the remote families of his race, we are led to regard these regular and systematic movements of the ocean as the agencies by which the earth was prepared for his reception, and as designed by Providence from the beginning to be the instruments of those changes in the face of the globe which were to precede the introduction of the human race, the great end of its creation.

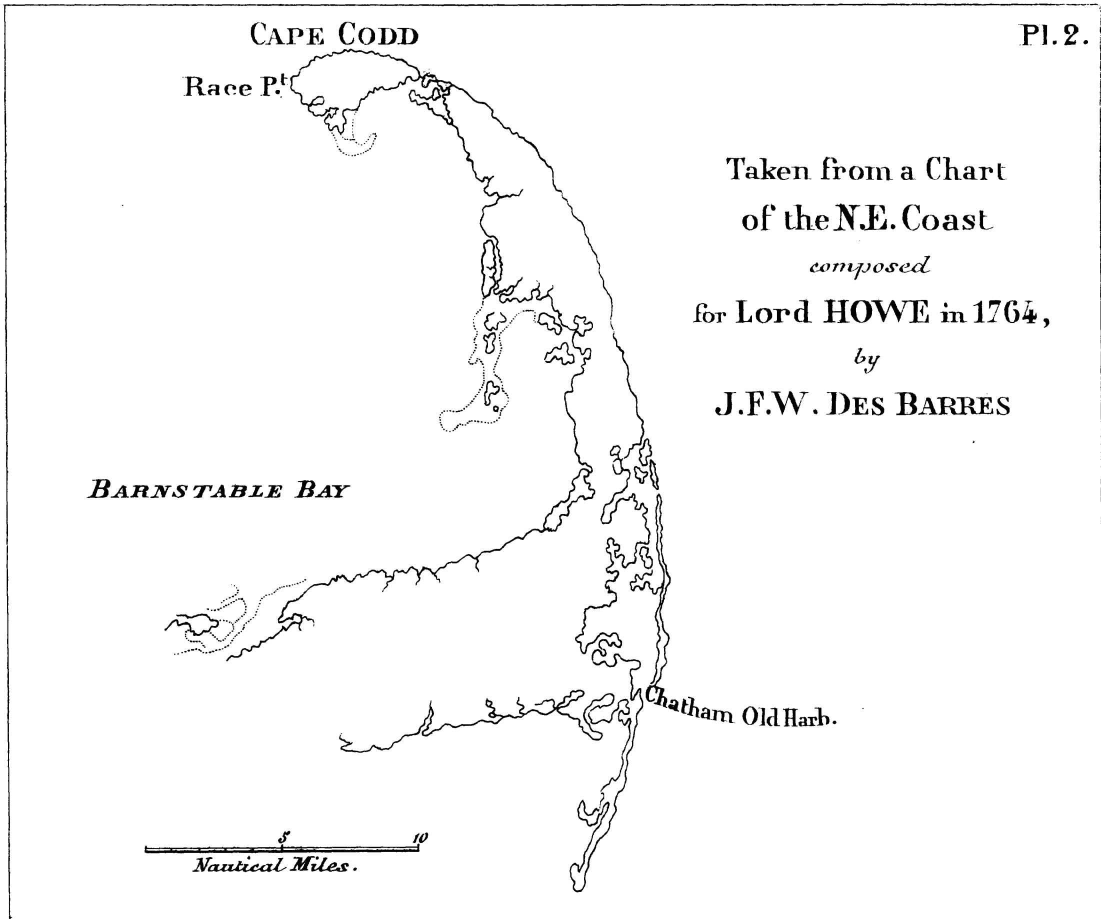
NOTE. — In the second section of this memoir, a particular description is given of the manner in which indentations along the coast are converted into ponds by the gradual formation of alluvial belts across their openings, the sand being deposited by the flood current. It is quite common to find in the drift of Cape Cod several of these ponds lying along the same valley, or depression, one within the other, and separated by bands, more or less broad, of sand and gravel finer than that of the hills. It may be supposed that, when the communication between the innermost pond and the sea was open, the current, eddying round a projecting point, continued at every successive tide to leave its burden, until finally an inclosure was formed by the junction of the belt to the opposite side of the bay. And so with the other ponds in succession. It has been already remarked that these ponds *are often deeper than the adjacent sea*, and without doubt the tendency will be to disunion at the shallowest parts. Profiting by what has been made known concerning the Aralo-Caspian basin by Sir Roderick I. Murchison, in his *Geology of Russia in Europe and the Ural Mountains*, an analogy of condition may perhaps be traced between the inland seas and lakes of Southern Russia and the East, and the diminutive ponds of New England. This is truly *parvis componere magna*, but nevertheless the sentiment concerning time, which Sir Roderick has adopted as his motto, belongs equally to its correlative space: — *Le temps qui nous manque, ne manque point à la nature.*

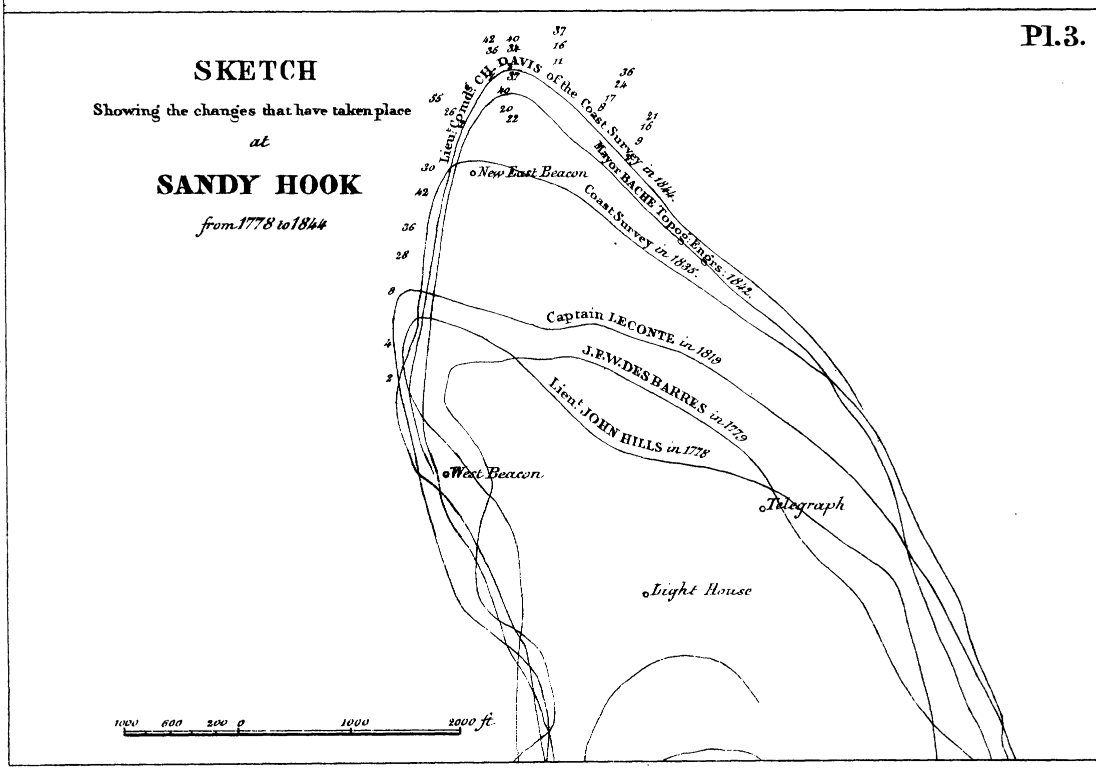
" Judging," he says, " from the organic remains collected from numerous parts of the whole area, there can be no sort of doubt that all the masses of water now separated from each other, from the Aral to the Black Sea inclusive, were formerly united to this vast pre-historical Mediterranean." The Caspian evidently was connected with the Black Sea through the Caucasian belt of sand, gravel, and shells, and the Aral and Caspian interminged their waters through the low, sandy desert of Khivah.

" The low level of the adjacent eastern districts would lead us to infer that it [this sea] spread over wide tracts in Asia now inhabited by Turkomans and Kirghis," but it is not certain whether the lakes in this direction are also included in the same geological formation. It is interesting to know that the transition from purely oceanic to brackish water deposits is indicated on the west (only) by a partial intermixture of shells of each type (pp. 297 et seq.) The subsequent diminution of this vast body of water to such a capacity as rendered possible the divisional deposits is a fruitful subject of speculation to the geologist, and is discussed by Sir Roderick Murchison.



Lith. of A. Sonrel, Cambridge, Mass.


Cape Codd
Pl. 2.
Race Pt.
Taken from a Chart
of the N.E. Coast
composed
for Lord HOWE in 1764,
by
J.F.W. Des Barres
Barnstable Bay
Chatham Old Harb.
5
10
Nautical Miles.


Pl.3.
SKETCH
Showing the changes that have taken place
at
SANDY HOOK
from 1778 to 1844
Lieut. Comdr. CH. DAVIS of the Coast Survey in 1844.
Major BACHE Topog. Engrs. 1842.
New East Beacon
Coast Survey in 1835.
Captain LECONTE in 1819
J.F.W. DES BARRES in 1779
Lieut. JOHN HILLS in 1778
West Beacon
Telegraph
Light House
1000
600
200
0
1000
2000 ft.